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SUBSTITUTE SPECIFICATION

The Clean Version

WEATHER-AGILE RECONFIGURABLE AUTOMATIC TARGET RECOGNITION SYSTEM

DEDICATORY CLAUSE

[0001]   The invention described herein may be manufactured, used and licensed by or for the Government for governmental purposes without the payment to us of any royalties thereon.

BACKGROUND OF THE INVENTION

[0002]   On many battlefields, well-known target signatures are distorted by real-world effects, such as various and varying environmental conditions. Further, new, heretofore-unknown targets emerge that need to be defined. As a consequence, updates of a target acquisition or automatic target recognition (ATR) knowledge base are and continue to be a necessity for autonomous precision strike weapons. Such autonomous precision strike weapons utilize all possible target sensing means except direct laser designation of the targets.

[0003]   ATR systems that use some type of pattern recognition need some form of knowledge or training database resident in the systems for proper operation. Since the performance of any ATR system is limited by these training data and often even known targets are obscured by camouflage and other means, most real-world applications require some real-time updates (i.e. retraining) of the target knowledge database. This requirement also holds true for any new mobile or fixed targets. This "real-time" retraining is referred to as rapid retraining or rapid target update.

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[0004]   In an ATR system, the typically required information for the pattern recognizer consists of target and background/clutter signatures in the electromagnetic band of interest. The robustness of ATR performance is usually quantified by correct classification of targets in some form, such as recognition or identification and false alarms defined as either clutter or misclassifications. The best ATR for any specific system application can be selected from known algorithms that are amenable to rapid retraining and also appropriate for the timeline for the specific application at hand. To maintain the ATR robustness through rapid target updating, however, the ATR must have the flexibility to be reconfigured in response to the target scene information provided by the surveillance means. Part of this updating process includes establishing metrics of the clutter in the target scene so that the criteria on ATR performance can be established for the specific target environment.

[0005]   In general, multiple simultaneous weapon engagements are desired to eliminate multiple targets in a very short period of time. The rapid retraining of multiple weapons is restricted by the limitations of available and compatible sensors.

SUMMARY OF THE INVENTION

[0006]   Applicants' ATR system is weather-agile because it is comprised of a first target sensing means, either singular or plural, that is (are) capable of surveilling the target scene in foul or fair weather, and a second target sensing means, comprised of a group of sensors. At least one sensor from the group comprising the second target sensing means is mounted on one of several available weapons. These sensors can also sense targets in either foul or fair weather. Applicants' ATR system makes it possible to use dissimilar sensors in surveillance and in the weapons, while not excluding the use of similar active or passive sensors when conditions allow.

[0007]   The first and second sensing means communicate through a control center so that ultimately, among the several weapons available, the most strategically located (based on its trajectory relative to the selected target) and equipped (relative to

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the weather) weapon is activated for the destruction of a selected target. The control center accomplishes the communication by receiving the sensed target signature from the first sensing means, processing the signature using database already resident in the center and transmitting the processed target signature to the weapon possessing the greatest potential for successfully destroying the target.

DESCRIPTION OF THE DRAWING

[0008]   Figure 1 illustrates the Weather-Agile Reconfigurable ATR System having multi-spectral target sensing means on both the surveillance platform and the weapons.

[0009]   Figure 2 shows the Reconfigurable ATR system wherein both the surveillance and weapon sensors are synthetic aperture radars (SAR's).

[0010]   Figure 3 shows the Reconfigurable ATR system wherein the primary target sensor on the surveillance platform is a SAR and the secondary target sensor on the weapon is a laser radar.

[0011]   Figure 4 shows the Reconfigurable ATR system wherein the primary target sensor is a SAR and the secondary target sensor is an electro-optical sensor.

[0012]   Figure 5 shows the Reconfigurable ATR system wherein both the surveillance and weapon sensors are electro-optical sensors.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0013]   Refer now to the drawing wherein like numbers represent like parts in each of the several figures, solid lines with arrowheads represent signal paths and dotted lines with arrowheads represent the weapon trajectory. With reference to the drawing, different combinations of various types of primary and secondary sensing means are presented for changeable climatic conditions.

[0014]   Figure 1 is a diagram of the Weather-Agile Reconfigurable ATR System having multi-spectral target sensing means on both the surveillance platform and on the

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weapons. The primary sensing means is multi-spectral sensor 101 mounted onto airborne surveillance platform 105 from which it surveils target scene 109 through any kind of weather that may exist between the platform and the target scene. From this surveillance activity, the multi-spectral sensor produces target signature information that is descriptive of the type of target detected. This target signature information is downlinked to control center 111, also through any kind of weather condition.

[0015]   The control center has therein pre-existing database which pertains to, among others, target spectra, terrain and material classification, topography, atmospheric correction for converting radiance to reflectance, the capabilities and limitations of the sensing means on the available weaponry and the location of the weaponry. The control center transmits this database, to the extent practical, to surveillance platform 105 to optimize the transfer between the primary sensing means and the control center of the most useful information for rapid retraining.

[0016]   Upon receipt of the target signature information, the control center processes (reformats) the information to discover the type and location of the detected target and selects, among available weapons 107, the particular weapon that is most likely to succeed in destroying the detected target. The likelihood of success is determined based on the location of the weapon, its predicted trajectory relative to the location of the target and the weapon's destructive capabilities. The selected weapon confirms to the control center the receipt of the update. Thereafter, the weapon is launched toward the target. In the embodiment shown in Figure 1, the suitability of secondary sensing means 103 on the weapon for detection of the target through the weather encompassing the trajectory is deemed irrelevant since it is a multi-spectral sensor capable of functioning in all weather conditions.

[0017]   Figure 2 shows the Reconfigurable ATR system wherein both the surveillance and weapon sensors are synthetic aperture radars (SAR) 201 and 203, respectively. Such active sensors of the same type being used together offers the highest potential for image matching of spatial features. If SAR sensors having different resolutions (example: higher resolution on the surveillance producing a finer or higher-

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resolution image, and lower resolution on the weapons producing a coarser or lower-resolution image) are used, the two different resolution images of the same scene can be fused using the method taught by Mario Costantini et al. in their article "The Fusion of Different Resolution SAR Images," in the *PROCEEDINGS OF THE IEEE*, vol. 85, No. 1, pages 139-146. The objective of the Costantini method is to fuse two different spatial resolution SAR images to provide a fused image with improved ability to detect point scatterers in a uniform background. Since SAR images are acquired in range-doppler coordinate system, both images must be acquired in this coordinate system. Both the high-resolution and the low-resolution instruments collecting the images are digital instruments, and the fusion process is pixel level fusion in contrast with other fusion methods; for example, feature level fusion. In the Costantini method, the fusion of the two images is carried out by obtaining the image which has the least mean square deviation from the finer-resolution image. The higher-resolution image may be viewed as the reference image on which the fusion process takes place, but a pre-requisite is that the two images be co-registered. The expected intensity of the lower resolution image is then constrained to be the local average of the expected intensity of the higher-resolution image. The relative variance of the two images is introduced to adaptively adjust the weight of intensity. The result sought is a reconstruction of the expected image intensity at the finer-resolution which is less noisy than that given by the finer-resolution image intensity above. The minimization problem with MN independent variables can be decomposed in MN/mn independent variables. So, in the Costantini method, a Cartesian coordinate system is used to describe an image surface in (x,y). From this surface, a (x,y) and ø (x,y) describe the amplitude and phases, respectively, of the signals received by the two digital instruments, one with a complex impulse response h (x,y) - the higher resolution instrument; and the second with a complex impulse response h' (x,y) - the lower resolution instrument. The "width" of the impulse response defines the spatial resolution of the two instruments. The imaging pixels of the two instruments are arranged in parallel with the coordinates of the imaging surface. The pixels of the higher

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resolution instrument have dimensions, Δx and Δy, with reference at x_0, y_0.   The following definition of symbols applies hereinafter:

x, y : the coordinates of the imaged surface; positive real numbers.

Δx, Δy : pixel dimensions of the higher resolution image; positive real numbers.

x_0, y_0 : the lower left corner of the imaged surface (the zero point of the coordinate system).

$x_i = x_0 + i\Delta x$ and $y_j = y_0 + j\Delta y$ refer to the i, j pixels of higher resolution image.

M, N refers to the higher resolution instrument pixel elements.

m, n refers to the lower resolution instrument pixels.

(i,j) refers to the higher resolution image.

(i', j') are the labels for the lower resolution instrument.

R_x, R_y are positive numbers defining the resolution of the higher resolution instrument along the two coordinates x, y.

Using the above, the pixels in the higher resolution instrument are identified as follows:

(1)   (i j), i = 0, 1, --- M - 1, j = 0, 1, -- N - 1

For the lower resolution instrument, the pixels are identified as:

(2)   (i' j'), i' = 0, 1 -- $\dfrac{M}{m}$ - 1, j' = 0, 1 -- $\dfrac{N}{n}$ - 1

Where $\dfrac{M}{m}$ and $\dfrac{N}{n}$ are the ratios between the coarser and finer resolution cells.

With the identification of the geometric relationship between the two-dimensional pixel array of the higher resolution instrument and imaging surface, the complex value of the image is:

$$C_{ij} = \int_0^a \int_{-\infty}^{\infty} h\,(x - x_i, y - y_i)\, a\,(x,y) \exp\,(i\varnothing(x,y))\, dx\, dy \quad \text{(higher resolution)}$$

The image intensity is:

$$I_{ij} = \left| C_{ij} \right| \quad \text{(higher resolution)}$$

(3) The expected value of image intensity is:

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$$\langle I_{ij} \rangle = \int_0^\infty \int_0^\infty \; |\; h(x\text{-}x_i, y\text{-}y_i)\;|^2 \; \left\langle [a(x,y)]^2 \right\rangle dxdy \quad \text{(higher resolution)}$$

From equation (2), the coordinates of the pixels of the lower resolution instrument are identified; which leads to:

(4) $\quad x_i' = x_0 + \dfrac{(m-1)\Delta x}{2} + i' m \Delta x$

(5) $\quad y'j = y_0 + \dfrac{(n-1)\Delta x}{2} + j' n \Delta y$

These two equations assume that the two images are co-registered. From this, the expected intensity of the lower resolution instrument is obtained:

(6) $\quad \langle I_{i'j'} \rangle = \int_0^\infty \int_0^\infty \; |\; h'\,(x\text{-}x_i', y\text{-}y_i')\;|^2 \; \left\langle [a(x,y)]^2 \right\rangle \; dxdy$

The two images of the same scene are statistically independent, and the relative variance of the two images are:

(7) $\quad v = \dfrac{\left\langle \left(I_{ij} - \langle I_{ij} \rangle \right)^2 \right\rangle}{\left\langle \left(I_{ij} \right) \right\rangle^2}$ $\qquad$ Higher Resolution Image $\quad$ (independent of i j)

(8) $\quad v = \dfrac{\left\langle \left(I_{i'j'} - \langle I_{i'j'} \rangle \right)^2 \right\rangle}{\left\langle \left(I_{i'j'} \right) \right\rangle^2}$ $\qquad$ Lower Resolution Image $\quad$ (independent of i' j')

The square of the absolute value of the impulse responses of the two instruments are:

(9) $\quad |h(x,y)|^2 = \dfrac{1}{R_x R_y} \;$ for $|x| \leq R_x, |y| \leq R_y$ $\qquad$ Higher Resolution Instrument

(10) $\quad$ and $\; |h'(x,y)|^2 = \dfrac{1}{mn} \; |h(x/m, y/m)|^2$ $\qquad$ Lower Resolution Instrument

By combining (3), (6), (9) and (10), the result is

(11) $\quad \left\langle I_{i'j'} \right\rangle = \dfrac{1}{mn} \; \sum_{i=i'm}^{(i'+1)m-1} \sum_{j=j'n}^{(j'+1)n-1} \left\langle I_{ij} \right\rangle$

That is, the expected intensity of the lower resolution image is the local average of the higher resolution image. The fusion of the two image intensities is obtained as the solution to the following minimization problem:

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(12) $\quad \{\begin{smallmatrix} min \\ X_{ij} \end{smallmatrix}\} \quad \sum\limits_{i=0}^{M-1} \sum\limits_{j=0}^{N-1} \left(X_{ij} - I_{ij}\right)^2$

Subject to the constraints:

(13) $\quad \dfrac{\sum\limits_{k=i'm}^{(i'+1)m-1} \sum\limits_{l=j'n}^{(j'+1)n-1} X_{kl}}{mn} = \dfrac{\dfrac{1}{v'} I_{i'j'} + \dfrac{1}{v} \sum\limits_{k=i'm}^{(i'+1)m-1} \sum\limits_{l=j'n}^{(j'+1)n-1}}{\dfrac{1}{v} + \dfrac{mn}{v}}$

And:

(14) $X_{ij} \geq 0$

Where, in (13) i=0, 1--M/m-1, j=0, 1---- N/n-1 - and in (14) i=0,1, --M-1 and j=0,1, ---N-1

Equation (13) enforces the condition that the expected image intensity of the coarser resolution instrument must be the appropriate weighted average (with weights $\dfrac{1}{v'}$ and $\dfrac{mn}{v}$ of the coarser resolution estimated from the two images. Equation (14) indicates that the intensity is always positive. The minimization problem with MN independent variables can be decomposed in MN/mn independent variables. The sub-problems are labeled: i' = 0, 1, --- M/m - 1, j' = 0, 1, ---N/n -1. The (i', j')th sub-problem is the following:

(15) $\quad \begin{smallmatrix} mm \\ X_{kl} \end{smallmatrix} \quad \sum\limits_{K=im}^{(i+1)m-1} \sum\limits_{l=j'n}^{(j'-1)n-1} \left(X_{kl} - I_{kl}\right)^2$

Subject to the constraints of (13) and

(16) $X_{kl} \geq 0$

Where, in (16) : k = i'm, i'm + 1, ---(i' + 1) m - 1

$\qquad\qquad$ l = j'n, j'n + 1 --- (j '+ 1) -1

By thusly performing a fusion of the images as taught by Costantini et al, a better match between the sensors can be achieved.

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[0018]   The SAR-to-SAR configuration is particularly useful when both sensors must operate in foul weather because when the weather is poor, electro-optical sensors or hyperspectral sensors provide little or no capability. In Figure 2, SAR imagery is collected over target scene 109 in foul weather indicated by clouds 205. In addition to clouds, the foul weather can be fog or rain. The SAR image collected must include both potential targets, confusers and clutter so that eventually a high level of precision strike can be performed with virtually zero false alarms and avoid unintended targets. The collected SAR imagery is compressed and down-linked to the control center with the position coordinates of the potential targets or "regions of interest" and the position of the surveillance platform relative to the available weapons. Upon receipt, the control center decompresses the imagery, performs coordinate transformation for a specific weapon trajectory and performs the discrimination and classification processes using synthetic discrimination function filter. From this is derived the target spatial information which is formatted to allow rapid retraining of weapons with synthetic aperture radar 203. It is noted that in the future, the control center itself may potentially be eliminated or bypassed and its functionality placed either at first or second sensing means or partitioned between the two. This direct communication between the sensing means would help minimize the latency and result in improved target elimination timeline.

[0019]   The target spatial information derived by the control center can also be transmitted to weapons with laser radar 301 or electro-optical or hyperspectral sensor 401, as illustrated in Figures 3 and 4, respectively, if the weather encompassing the selected weapon trajectory is fair. A method for fusing SAR and hyperspectral image data sets over the same area is taught by Su May Hsu et al. in "SAR and HSI Data Fusion for Counter CC&D," *The Record of the IEEE 1999 Radar Conference*, pages 218-220. The article describes the Hsu method as it was practiced on a collection of images of suspected target vehicles obtained by the Foliage Penetration SAR and hyperspectral images (HSI) of camouflage nets and other background terrain characteristics obtained by the hyperspectral sensor. In the Hsu method, the SAR and

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HSI data are first processed separately for detection of target objects and terrain classification, respectively. SAR data is processed with pixel grouping and thresholding for target detection. The terrain classification and spectral feature extraction in HSI data is accomplished by reducing the dimensionality of the HSI data. The reduction of the dimensionality is performed by first obtaining Eigenvectors and then using the Eigenvectors to transform HSI data into principal components, also known as Eigenimages. Principal component transform allows the segregation of noise components and the determination of the inherent dimensionality of the HSI data. Using iso-data clustering, terrain features, such as trees, roads and camouflage nets can be distinguished and mapped. To combine the SAR and HSI data, co-registration is first performed with reference to terrain features using scaling, rotation and translation operations. Then, fusion process follows based on the co-registered images. SAR detections that coincide with HSI identifications as trees or camouflage nets, for example, are eliminated as false alarms, thus increasing the accuracy of the target detection by SAR.

[0020]   If the weather conditions allow, use of purely passive sensors such as electro-optical sensors 501 and 401 is highly desirable because it minimizes the potential of alerting the targets during multiple simultaneous weapon engagements. This is illustrated in Figure 5. Substitution of the electro-optical sensors with hyperspectral sensors may afford the ability to detect specific materials used in a target object.

[0021]   The embodiment, depicted in Figure 1, utilizing multi-spectral sensors both on the surveillance platform and on the non-reusable weapons may entail substantial costs. An alternative is to use simultaneously the combinations of various types of primary (on the surveillance platform) and secondary (on the weapons) sensing means as described above with reference to Figures 2 through 5. Many surveillance platforms having thereon various types of primary sensing means may be deployed, all communicating with a common control center. Likewise, many groups of weapons can be positioned at various locations, each group in turn comprising multiple weapons

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having different secondary sensing means. In this way, great flexibility is built into the Weather-Agile Reconfigurable ATR system to achieve the least wasteful and most accurate precision strikes against selected targets.

[0022]   Although a particular embodiment and form of this invention has been illustrated, it is apparent that various modifications and embodiments of the invention may be made by those skilled in the art without departing from the scope and spirit of the foregoing disclosure. Accordingly, the scope of the invention should be limited only by the claims appended hereto.

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SUBSTITUTE SPECIFICATION

The Marked-Up Version

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BACKGROUND OF THE INVENTION

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band of interest. The robustness of ATR performance is usually quantified by correct
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system application can be selected from known algorithms that are amenable to rapid
retraining and also appropriate for the timeline for the specific application at hand. To
maintain the ATR robustness through rapid target updating, however, the ATR must
have the flexibility to be reconfigured in response to the target scene information
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metrics of the clutter in the target scene so that the criteria on ATR performance can be
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eliminate multiple targets in a very short period of time. The rapid retraining of
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first target sensing means, either singular or plural, that is (are) capable of surveilling
the target scene in foul or fair weather, and a second target sensing means, comprised of
a group of sensors. At least one sensor from the group comprising the second target
sensing means is mounted on one of several available weapons. These sensors can also
sense targets in either foul or fair weather. Applicants' ATR system makes it possible
to use dissimilar sensors in surveillance and in the weapons, while not excluding the
use of similar active or passive sensors when conditions allow.

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center so that ultimately, among the several weapons available, the most strategically
located (based on its trajectory relative to the selected target) and equipped (relative to

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the weather) weapon is activated for the destruction of a selected target. The control center accomplishes the communication by receiving the sensed target signature from the first sensing means, processing the signature using database already resident in the center and transmitting the processed target signature to the weapon possessing the greatest potential for successfully destroying the target.

DESCRIPTION OF THE DRAWING

[0008]   Figure 1 illustrates the Weather-Agile Reconfigurable ATR System having multi-spectral target sensing means on both the surveillance platform and the weapons.

[0009]   Figure 2 shows the Reconfigurable ATR system wherein both the surveillance and weapon sensors are synthetic aperture radars (SAR's).

[0010]   Figure 3 shows the Reconfigurable ATR system wherein the primary target sensor on the surveillance platform is a SAR and the secondary target sensor on the weapon is a laser radar.

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[0012]   Figure 5 shows the Reconfigurable ATR system wherein both the surveillance and weapon sensors are electro-optical sensors.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0013]   Refer now to the drawing wherein like numbers represent like parts in each of the several figures, solid lines with arrowheads represent signal paths and dotted lines with arrowheads represent the weapon trajectory. With reference to the drawing, different combinations of various types of primary and secondary sensing means are presented for changeable climatic conditions.

[0014]   Figure 1 is a diagram of the Weather-Agile Reconfigurable ATR System having multi-spectral target sensing means on both the surveillance platform and on the

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weapons. The primary sensing means is multi-spectral sensor 101 mounted onto airborne surveillance platform 105 from which it surveils target scene 109 through any kind of weather that may exist between the platform and the target scene. From this surveillance activity, the multi-spectral sensor produces target signature information that is descriptive of the type of target detected. This target signature information is downlinked to control center 111, also through any kind of weather condition.

[0015]   The control center has therein pre-existing database which pertains to, among others, target spectra, terrain and material classification, topography, atmospheric correction for converting radiance to reflectance, the capabilities and limitations of the sensing means on the available weaponry and the location of the weaponry. The control center transmits this database, to the extent practical, to surveillance platform 105 to optimize the transfer between the primary sensing means and the control center of the most useful information for rapid retraining.

[0016]   Upon receipt of the target signature information, the control center processes (reformats) the information to discover the type and location of the detected target and selects, among available weapons 107, the particular weapon that is most likely to succeed in destroying the detected target. The likelihood of success is determined based on the location of the weapon, its predicted trajectory relative to the location of the target and the weapon's destructive capabilities. The selected weapon confirms to the control center the receipt of the update. Thereafter, the weapon is launched toward the target. In the embodiment shown in Figure 1, the suitability of secondary sensing means 103 on the weapon for detection of the target through the weather encompassing the trajectory is deemed irrelevant since it is a multi-spectral sensor capable of functioning in all weather conditions.

[0017]   Figure 2 shows the Reconfigurable ATR system wherein both the surveillance and weapon sensors are synthetic aperture radars (SAR) 201 and 203, respectively. Such active sensors of the same type being used together offers the highest potential for image matching of spatial features. If SAR sensors having different resolutions (example: higher resolution on the surveillance producing a finer or higher-

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resolution image, and lower resolution on the weapons producing a coarser or lower-resolution image) are used, the two different resolution images of the same scene can be fused using the method taught by Mario Costantini et al. in their article "The Fusion of Different Resolution SAR Images," in the ~~PROCEEDINGS OF THE IEEE~~ *PROCEEDINGS OF THE IEEE*, vol. 85, No. 1, pages 139-146. The objective of the Costantini method is to fuse two different spatial resolution SAR images to provide a fused image with improved ability to detect point scatterers in a uniform background. Since SAR images are acquired in range-doppler coordinate system, both images must be acquired in this coordinate system. Both the high-resolution and the low-resolution instruments collecting the images are digital instruments, and the fusion process is pixel level fusion in contrast with other fusion methods; for example, feature level fusion. In the Costantini method, the fusion of the two images is carried out by obtaining the image which has the least mean square deviation from the finer-resolution image. The higher-resolution image may be viewed as the reference image on which the fusion process takes place, but a pre-requisite is that the two images be co-registered. The expected intensity of the lower resolution image is then constrained to be the local average of the expected intensity of the higher-resolution image. The relative variance of the two images is introduced to adaptively adjust the weight of intensity. The result sought is a reconstruction of the expected image intensity at the finer-resolution which is less noisy than that given by the finer-resolution image intensity above. The minimization problem with MN independent variables can be decomposed in MN/mn independent variables. So, in the Costantini method, a Cartesian coordinate system is used to describe an image surface in (x,y). From this surface, a (x,y) and $\phi(x,y)$ describe the amplitude and phases, respectively, of the signals received by the two digital instruments, one with a complex impulse response $h(x,y)$ - the higher resolution instrument; and the second with a complex impulse response $h'(x,y)$ - the lower resolution instrument. The "width" of the impulse response defines the spatial resolution of the two instruments. The imaging pixels of the two instruments are arranged in parallel with the coordinates of the imaging

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surface. The pixels of the higher resolution instrument have dimensions, Δx and Δy, with reference at x_0, y_0. The following definition of symbols applies hereinafter:

      x, y : the coordinates of the imaged surface; positive real numbers.

      Δx, Δy : pixel dimensions of the higher resolution image; positive real numbers.

      x_0, y_0 : the lower left corner of the imaged surface (the zero point of the coordinate system).

      $x_i = x_0 + i\Delta x$ and $y_j = y_0 + j\Delta y$ refer to the i, j pixels of higher resolution image.

      M, N refers to the higher resolution instrument pixel elements.

      m, n refers to the lower resolution instrument pixels.

      (i,j) refers to the higher resolution image.

      (i', j') are the labels for the lower resolution instrument.

      R_x, R_y are positive numbers defining the resolution of the higher resolution instrument along the two coordinates x, y.

Using the above, the pixels in the higher resolution instrument are identified as follows:

(1)   (i j), i = 0, 1, --- M - 1, j = 0, 1, -- N - 1

For the lower resolution instrument, the pixels are identified as:

(2)   (i' j'), $i' = 0, 1 -- \dfrac{M}{m} - 1, j' = 0, 1 -- \dfrac{N}{n} - 1$

Where $\dfrac{M}{m}$ and $\dfrac{N}{n}$ are the ratios between the coarser and finer resolution cells.

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With the identification of the geometric relationship between the two-dimensional pixel array of the higher resolution instrument and imaging surface, the complex value of the image is:

$$C_{ij} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} h(x - x_i, y - y_i)\, a(x,y) \exp(i\emptyset(x,y))\, dx\, dy \quad \text{(higher resolution)}$$

The image intensity is:

$$I_{ij} = \left| C_{ij} \right| \quad \text{(higher resolution)}$$

(3) The expected value of image intensity is:

$$\langle I_{ij} \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} |h(x - x_i, y - y_i)|^2 \left\langle [a(x,y)]^2 \right\rangle dx\, dy \quad \text{(higher resolution)}$$

From equation (2), the coordinates of the pixels of the lower resolution instrument are identified; which leads to:

$$(4) \quad x_i' = x_0 + \frac{(m-1)\Delta x}{2} + i' m \Delta x$$

$$(5) \quad y_j' = y_0 + \frac{(n-1)\Delta x}{2} + j' n \Delta y$$

These two equations assume that the two images are co-registered. From this, the expected intensity of the lower resolution instrument is obtained:

$$(6) \quad \langle I_{i'j'} \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} |h'(x - x_i', y - y_j')|^2 \left\langle [a(x,y)]^2 \right\rangle dx\, dy$$

The two images of the same scene are statistically independent, and the relative variance of the two images are:

$$(7) \quad v = \frac{\left\langle \left(I_{ij} - \langle I_{ij} \rangle \right)^2 \right\rangle}{\left\langle I_{ij} \right\rangle^2} \qquad \text{Higher Resolution Image} \quad \text{(independent of i j)}$$

$$(8) \quad v = \frac{\left\langle \left(I_{i'j'} - \langle I_{i'j'} \rangle \right)^2 \right\rangle}{\left\langle I_{i'j'} \right\rangle^2} \qquad \text{Lower Resolution Image} \quad \text{(independent of i' j')}$$

The square of the absolute value of the impulse responses of the two instruments are:

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(9) $|h(x,y)|^2 = \dfrac{1}{RxRy}$ for $|x| \leq Rx, |y| \leq Ry$ Higher Resolution Instrument

(10) and $|h'(x,y)|^2 = \dfrac{1}{mn} |h(x/m, y/m)|^2$ Lower Resolution Instrument

By combining (3), (6), (9) and (10), the result is

(11) $\left\langle J_{i'j'} \right\rangle = \dfrac{1}{mn} \displaystyle\sum_{i=i'm}^{(i'+1)m-1} \sum_{j=j'n}^{(j'+1)n-1} \cdot \left\langle I_{ij} \right\rangle$

That is, the expected intensity of the lower resolution image is the local average of the higher resolution image. The fusion of the two image intensities is obtained as the solution to the following minimization problem:

(12) $\displaystyle\left\{ \begin{matrix} min \\ X_{ij} \end{matrix} \right\} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left(X_{ij} - I_{ij} \right)^2$

Subject to the constraints:

(13) $\dfrac{\displaystyle\sum_{k=i'm}^{(i'+1)m-1} \sum_{l=j'n}^{(j'+1)n-1} X_{kl}}{mn} - \dfrac{\dfrac{1}{v'} 1_{i'j'} + \dfrac{1}{v} \displaystyle\sum_{k=i'm}^{(i'+1)m-1} \sum_{l=j'n}^{(j'+1)n-1}}{\dfrac{1}{v} + \dfrac{mn}{v}}$

And:

(14) $X_{ij} \geq 0$

Where, in (13) i=0, 1--M/m-1, j=0, 1---- N/n-1 - and in (14) i=0,1, --M-1 and j=0,1, ---N-1

Equation (13) enforces the condition that the expected image intensity of the coarser resolution instrument must be the appropriate weighted average (with weights $\dfrac{1}{v'}$ and

$\dfrac{mn}{v}$ of the coarser resolution estimated from the two images. Equation (14) indicates

that the intensity is always positive. The minimization problem with MN independent variables can be decomposed in MN/mn independent variables. The sub-problems are

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labeled: i' = 0, 1, --- M/m - 1, j' = 0, 1, ---N/n -1. The (i', j')th sub-problem is the following:

$$(15) \quad \frac{mm}{X_{kl}} - \sum_{k=i'm}^{(i'+1)m-1} \sum_{l=j'n}^{(j'-1)n-1} \cdot (X_{kl} - I_{kl})^2$$

Subject to the constraints of (13) and

(16) $X_{kl} \geq 0$

Where, in (16) : k = i'm, i'm + 1, ---(i' + 1) m - 1

l = j'n, j'n + 1 --- (j '+ 1) -1

By ~~fusing~~ thusly performing a fusion of the images as taught by Costantini et al, a better match between the sensors can be achieved. ~~Accordingly, the fusion techniques described in the article are incorporated herein.~~

[0018]   The SAR-to-SAR configuration is particularly useful when both sensors must operate in foul weather because when the weather is poor, electro-optical sensors or hyperspectral sensors provide little or no capability. In Figure 2, SAR imagery is collected over target scene 109 in foul weather indicated by clouds 205. In addition to clouds, the foul weather can be fog or rain. The SAR image collected must include both potential targets, confusers and clutter so that eventually a high level of precision strike can be performed with virtually zero false alarms and avoid unintended targets. The collected SAR imagery is compressed and down-linked to the control center with the position coordinates of the potential targets or "regions of interest" and the position of the surveillance platform relative to the available weapons. Upon receipt, the control center decompresses the imagery, performs coordinate transformation for a specific weapon trajectory and performs the discrimination and classification processes using synthetic discrimination function filter. From this is derived the target spatial information which is formatted to allow rapid retraining of weapons with synthetic aperture radar 203. It is noted that in the future, the control center itself may potentially be eliminated or bypassed and its functionality placed either at first or second sensing means or partitioned between the two. This direct communication between the sensing

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means would help minimize the latency and result in improved target elimination
timeline.

[0019]   The target spatial information derived by the control center can also be
transmitted to weapons with laser radar 301 or electro-optical or hyperspectral sensor
401, as illustrated in Figures 3 and 4, respectively, if the weather encompassing the
selected weapon trajectory is fair. A method for fusing SAR and hyperspectral image
data sets over the same area is taught by Su May Hsu et al. in "SAR and HSI Data
Fusion for Counter CC&D," ~~The Record of the IEEE 1999 Radar Conference~~ *The
Record of the IEEE 1999 Radar Conference*, pages 218-220. The article describes the
Hsu method as it was practiced on a collection of images of suspected target vehicles
obtained by the Foliage Penetration SAR and hyperspectral images (HSI) of
camouflage nets and other background terrain characteristics obtained by the
hyperspectral sensor. In the Hsu method, the SAR and HSI data are first processed
separately for detection of target objects and terrain classification, respectively. SAR
data is processed with pixel grouping and thresholding for target detection. The terrain
classification and spectral feature extraction in HSI data is accomplished by reducing
the dimensionality of the HSI data. The reduction of the dimensionality is performed
by first obtaining Eigenvectors and then using the Eigenvectors to transform HSI data
into principal components, also known as Eigenimages. Principal component transform
allows the segregation of noise components and the determination of the inherent
dimensionality of the HSI data. Using iso-data clustering, terrain features, such as
trees, roads and camouflage nets can be distinguished and mapped. To combine the
SAR and HSI data, co-registration is first performed with reference to terrain features
using scaling, rotation and translation operations. Then, fusion process follows based
on the co-registered images. SAR detections that coincide with HSI identifications as
trees or camouflage nets, for example, are eliminated as false alarms, thus increasing
the accuracy of the target detection by SAR. ~~Therefore, the method of co-registering
the images using references to terrain features, as described in the Hsu article, is
incorporated herein.~~

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[0020]   If the weather conditions allow, use of purely passive sensors such as
electro-optical sensors 501 and 401 is highly desirable because it minimizes the
potential of alerting the targets during multiple simultaneous weapon engagements.
This is illustrated in Figure 5. Substitution of the electro-optical sensors with
hyperspectral sensors may afford the ability to detect specific materials used in a target
object.

[0021]   The embodiment, depicted in Figure 1, utilizing multi-spectral sensors
both on the surveillance platform and on the non-reusable weapons may entail
substantial costs. An alternative is to use simultaneously the combinations of various
types of primary (on the surveillance platform) and secondary (on the weapons) sensing
means as described above with reference to Figures 2 through 5. Many surveillance
platforms having thereon various types of primary sensing means may be deployed, all
communicating with a common control center. Likewise, many groups of weapons can
be positioned at various locations, each group in turn comprising multiple weapons
having different secondary sensing means. In this way, great flexibility is built into the
Weather-Agile Reconfigurable ATR system to achieve the least wasteful and most
accurate precision strikes against selected targets.

[0022]   Although a particular embodiment and form of this invention has been
illustrated, it is apparent that various modifications and embodiments of the invention
may be made by those skilled in the art without departing from the scope and spirit of
the foregoing disclosure. Accordingly, the scope of the invention should be limited
only by the claims appended hereto.